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THE ATTENTIONAL CAPTURE OF COLOUR IN VISUAL INTERFACE DESIGN: A CONTROLLED-ENVIRONMENT STUDY

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Abstract

The use of colour is an integral component in visual interface design for creating separation between objects and for conveying meaning. It has previously been established that colours can be separated in a hierarchy of primary colours and secondary colours, and that colours are consistently associated with specific mood tones. However, it has thus far not been investigated whether these two factors, which we refer to as the perception-primacy and emotion-conveyance, are associated with attentional capture in a congruent manner. To investigate this, we conducted a visual search task study in a controlled environment, in which 11 participants scanned a 20 item display for a coloured target amongst coloured distractors. We found evidence to support that primary colours capture attention significantly more than secondary colours, and inconclusive evidence that colours convey their meaning at a sufficiently early level of processing to influence attention. We end by discussing implications of our results for design practice and research in psychology.

Keywords: Attention in design, Emotional design, Communication, Human behaviour in design, Visualisation

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1 INTRODUCTION

The design of visual interfaces has become increasingly important as the prevalence of computer technology widens. For example, sectors with control rooms, such as the nuclear, are moving away from physical levers, barometers and switches towards computer-integrated systems with computer screens as the main access and information point (Lau et al., 2008; Braseth and Øritsland, 2013). In such contexts, or in everyday life, designs that allows for swift and effective behaviour are essential for performance. To achieve this, designers must create interfaces where the visual objects are clearly distinguished and easy to find. Research has shown that our ability to see in colours is particularly efficient for distinguishing between objects (Vazques et al., 2010). From an evolutionary perspective, the ability to see colour has allowed us many advantages, beyond the aesthetic, such as easily finding wild berries in a bush (see Figure 1). In the same vein, designers may use colour to make objects easily detectable in a crowded interface.

In this paper, we present a study of the interactions between colours and attention to see which colours best facilitate search tasks, and to aid designers in a world of visual interfaces. We measured attentional capture as a function of reaction time in a visual search task with regards to what we call the perception-primacy account, which states that there is a set of primary and secondary colours that cause differences in attentional capture, and the emotion-conveyance account, which states that colours convey emotions at an early enough stage to influence attentional capture.

This paper consists of five sections: Section one introduced the topic. Section two discusses the perception-primacy and emotional-conveyance accounts. Section three describes the methods of the controlled-environment experiment that we conducted to test the accounts. Section four shows the statistical analysis of the results. Section five discusses the results and suggests impacts for design and psychology.

2 BACKGROUND

2.1 Colour in the Eye and in Art

The colours we see are the result of white light being reflected on surfaces of the objects we are looking at. Differences in colour arise from differences in the wavelengths of lights that the various objects absorb: a blue object absorbs all other wavelengths than blue, a yellow object absorbs all wavelengths other than yellow etc.. White is the colour shown when light is perfectly reflected, whereas black is the colour that arises when all wavelengths are absorbed. Our retinas contain a myriad of photoreceptive cells commonly referred to as rods and cones. Of these, cones are selectively responsive to either red, green, or blue wavelengths of light. The reactions of these cells are combined by the brain to what we experience as colour (Gazzaniga, 2009; Ware, 2010).

Figure 1. Finding berries with and without colour vision

In art and design, colours are typically divided into primary and secondary colours and arranged in what is commonly referred to as a colour wheel such as the one shown in Figure 2. The primary colours (red, blue and yellow) are referred to as such due to the properties of pigments: When combining pigments, one will progressively move towards a colour that absorbs more wavelengths, ending in black. However, one can produce all the colours of the rainbow by combining red, blue and yellow in the correct manner. Conversely, none of these three colours can be achieved by combining any other sets of colours, thereby establishing them as primary. Secondary colours are then those colours that are immediate derivatives of mixing the primary colours (Harkness, 2005). While the pigment-based definition is more prevalent, it is to be underlined that other definitions of what is primary and secondary colours are equally viable, as many systems (including, as mentioned above, our visual system) is able to create all colours through a combination of red, blue and green light.

2.2 Colour and Emotion

Beyond the direct use for separating objects, colours provide a powerful way for visual designers to convey emotion and meaning. Early studies from psychology have verified that colours can reliably be associated with certain mood tones: Red is most frequently associated with exciting, defending and defying/hostile moods, blue with soothing and secure, yellow and orange with stimulating, cheerful and exciting moods, green with calm and soothing and purple with dignified and stately moods (Wexner, 1954; Murray and Deabler, 1957; Schaie, 1961a, 1961b). More recently, studies from the design literature have shown that green, blue and white colours are more effective at signalling environmental friendliness for cars than were red and black (Lee et al., 2015) and that white is perceived as being more elegant than other colours (Na and Suk, 2014). Another avenue for conveying meaning lies in typical use of colours: For example, red is used for "stop" in traffic lights and is used in warning signs, whereas green means "go" in traffic and is used for recycling badges. The efficacy of using colour for emotional conveyance is further supported by in-company research (Gillet, 2014). Applying colours that fit with the desired conveyed meaning or that induce the desired mood is thus crucial and common among designers to use when creating a visual profile (Page et al., 2012). Furthermore, research from the design community has established the importance and prevalence of colour in creating designs for mood states (Desmet, 2015).

However, the level of processing required for the conveying of this meaning has thus far yet to be investigated. Is the emotion conveyed at an early stage, before attention is directed, or only after conscious processing has been applied? This question is particularly interesting, as other emotional stimuli have been shown to capture attention at an early stage of processing and thereby to capture attention. For example, Öhman et al. (2001) found that snake and spider stimuli captures attention more than flower and mushroom stimuli, which was later echoed by Brosch and Sharma (2005), who found equivalent results with modern stimuli (guns and syringes vs cups and mobile phones). Similar effects have been produced in numerous studies, albeit with varying effect sizes depending on the specific stimuli used (e.g. Koster et al., 2004; Huang et al., 2008; Hodsoll et al., 2011). Should colours convey their meaning at an early stage of processing as well, they would therefore be expected to direct attention in a manner congruent to their associated emotion.

2.3 The Attentional Capture of Colour

Thus far, studies have focused only on whether colours capture attention at an early stage, showing different results depending on the experimental setup (Folk et al., 1994; Theeuwes, 1994; Müller et al., 2009). However, based on the evidence described above, we propose two separate accounts that, if they hold true, would result in differences in performance in a visual search task: The perception-primacy account and the emotion-conveyance account.

The perception-primacy account states that there is, as argued above, a set of primary and secondary colours, and of that colours in a higher hierarchy will be treated preferentially in the attention-system. We investigate here both whether the biologically and artistically founded notions of primary colours. Should the perception-primacy account hold true, red, green and yellow or red, green and blue (depending on whether one adopts the biological primary colours or artistic primary colours respectively) should be treated preferentially and thus capture attention more. In turn, this would be visible through faster search times for these colours when they are the target of a visual search task, and slower average search time if they are present as distractors.

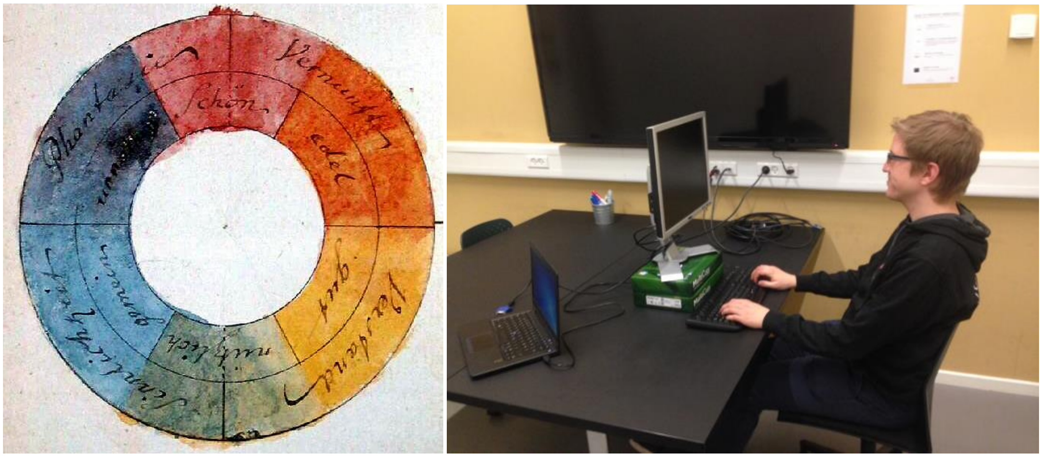

Figure 2. (left): The Colour Wheel as depicted by Johannes Wolfgang Goethe in his book Theory of Colours (1809), (right): The experiment set-up

The emotion-conveyance account states that colours convey emotions sufficiently strongly and at a sufficiently early stage in processing that it influences attentional capture. Specifically, we investigate the hypothesis that red, yellow and orange, which have generally been associated with 'action-moods' (excitement, hostility, defiance) would capture attention more than green, blue and purple, which have generally been associated with soothing or relaxing moods. As with the perception-primacy account, this would result in faster average search-times if these colours are the target, and slower average search-time if they are distractors.

3 METHODS

11 students (average age 20.9, 3 female) were recruited through an e-mail sign-up sheet distributed in person by the authors in lectures at the Technical University of Denmark. Participants were included if they were between 18 and 30 years old, had normal or corrected to normal eye-sight and did not suffer from any disorders that affect the attention system, such as ADHD.

The experiments were conducted on a Lenovo or Dell laptop computer using the E-Prime 2.0 software for Windows. The experiment was displayed on a Dell 18" monitor and participants responded via an external, USB-connected keyboard. The experiment was conducted in small quiet room with a fluorescent ceiling lamp above the participant and backlight from a glass door as the light sources. Upon arrival participants were greeted and asked to fill out a compliance form to verify that they complied with the inclusion criterion, and to give permission for the data to be used in publication. Participants were then seated ~60 cm away from the screen and with their eyes in line with the centre of the screen. Participants were furthermore equipped with Tobii Eye-Tracking glasses for the entire duration of the experiment (these results will not be reported here due to the scope of this paper). Figure 3 shows the experimental set-up.

The experiment consisted of a training block (15 trials) and experiment block (540 trials). Each trial proceeded as follows: First, a screen appeared for 1500ms, which instructed the participant which target to search for in the following task. Second, a black cross appeared in the middle of the screen for 1000ms, which the participant had been instructed to fixate on whenever it appeared. Third, a display containing 20 coloured circles appeared until the participant responded with the left keyboard arrow-key if the target was present, or the right keyboard arrow-key if the target was absent. The construction of these displays is elaborated on below. Fourth and finally, a review screen appeared which showed the participants their reaction time for the specific trial as well as their accuracy across all trials, and an instruction that the next trial could be started using the keyboard's spacebar. Figure 4 shows the experiment procedure.

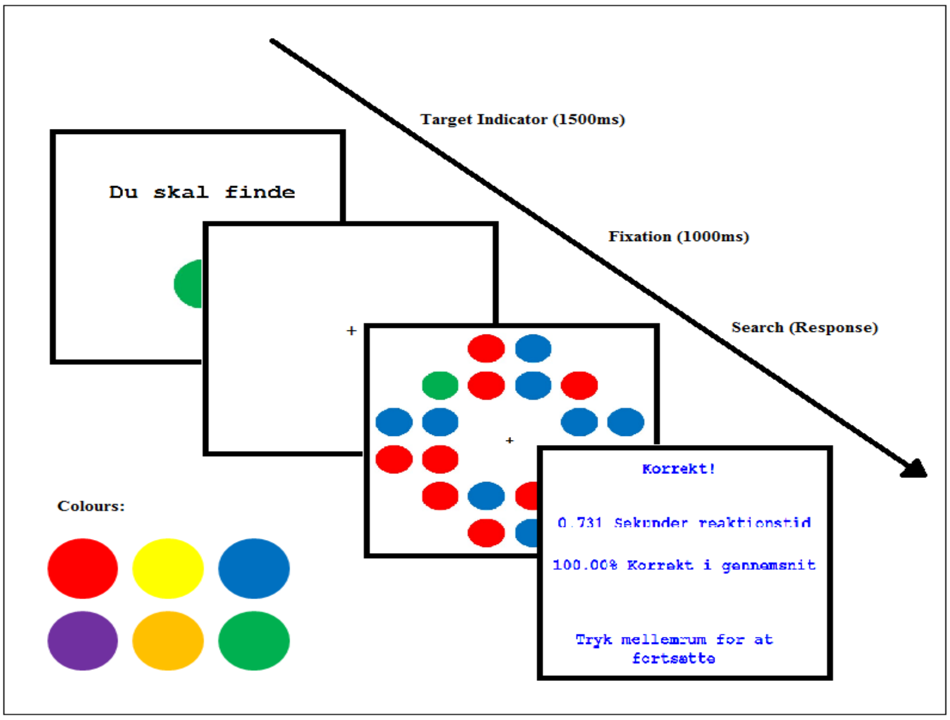

Figure 3. The experiment procedure (sample text in Danish): First, the participant is given the target colour. Second, the participant fixates on a cross in the centre of the screen. Third, the participant scans the display and responds whether the target is there or not. Fourth, the participant is given performance feedback

All stimuli displays were newly created for the experiment using MS Powerpoint and E-Prime 2.0 for Windows. A total of 360 target-present displays (2/3) and 180 target-absent displays (1/3) were created using the three primary and three secondary colours. The target-present displays were constructed each colour appeared as target with all other colours as distractors and so that the target appeared both in the inner and outer circle of the display. The distractors consisted of circles of one, two, three or four different colours and were balanced so that each of the distracting colours was approximately equally represented. The locations of both targets and specific distractor colours were randomly assigned using MS Excel's = RANDOM function. The target-absent trials were included to ensure that participants had to scan the display thoroughly before responding. They were created in the same manner as target-present displays (albeit with no target).

4 RESULTS

All analyses were conducted in the IBM SPSS statistics package v24 for Windows. The average RT was 513.73 milliseconds (ms) with a standard deviation of 156.83ms. Results were considered significant at $\alpha = 0.05$. The experiment lasted 30-35 minutes, including training, and participants showed no difference in performance as the experiment progressed. There was no significant effects of age (Spearman's $\rho = 0.25$, $p = 0.461$) or gender (Mann-Whitney $U = 17$, $p = 0.376$).
To prepare the dataset for analysis, z-values were computed for reaction time data for all responses across all participants and conditions. In total, 90 data entries were removed due to having a z-value larger than 4. As further investigation of the data showed no systematic reason for these very slow responses, it was concluded that they were due to external factors. This left a total of 14859 data entries for analysis. The analyses below are based on these data entries averaged and partitioned with respect to the participants and the specified conditions. Given that all participants had responded to all conditions, the analyses were conducted using Repeated Measures ANOVA and, if the ANOVA was significant, follow-up paired t-tests. These tests were adequate, despite the small sample size, as reaction time data was normally distributed for all parameters.

4.1 Effect of Target Colour

First, the effect of target colour on reaction time irrespective of distractor colour was analysed. A Repeated Measures ANOVA across all six target colour conditions revealed that there was a significant difference ($F_{5,50} = 18.25$, $p < 0.001$) in reaction time across the colours. Follow-up t-tests were therefore conducted to elucidate this difference. Figure 5 shows a graphical representation of the means analysed, and the results are summarized in Table 1.

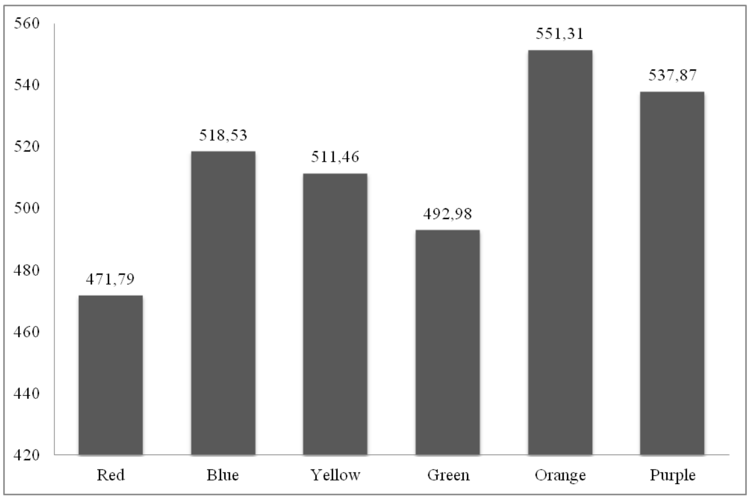

Figure 4. Reaction times (ms) for the target colours irrespective of distractor colours

Red targets were found significantly faster than blue targets (46.74 ms, $t_{10} = 5.48$, $p < 0.001$), yellow targets (39.67 ms, $t_{10} = 8.35$, $p < 0.001$), green targets (21.19 ms, $t_{10} = 6.12$, $p < 0.001$), orange targets (79.52 ms, $t_{10} = 6.55$, $p < 0.001$) and purple targets (39.77 ms, $t_{10} = 8.35$, $p < 0.001$).

Blue targets were found significantly slower than red targets (46.74 ms, t(10)=5.48, $p < 0.001$) and green targets (25.55 ms, $t_{10} = 3.02$, $p = 0.013$) and found significantly faster than orange targets (32.78ms, $t_{10} = 2.69$ $p = 0.023$) and purple targets (19.34 ms, $t_{10} = 3.25$, $p = 0.009$). There was no significant difference in reaction time between blue and yellow targets (7.07 ms, $t_{10} = 0.88$, $p = 0.402$).

Yellow targets were found significantly slower than red targets (39.77 ms, $t_{10} = 8.35$, $p < 0.001$) and green targets (18.48 ms, $t_{10} = 3.91$, $p = 0.003$) and found significantly faster than orange targets (39.85 ms, $t_{10} = 4.24$, $p = 0.002$) and purple targets (26.41 ms, $t_{10} = 2.56$, $p = 0.028$). There was no significant difference in reaction time between blue and yellow targets (7.07 ms, $t_{10} = 0.88$, $p = 0.402$).

Green targets were found significantly slower than red targets (21.19 ms, $t_{10} = 6.12$, $p < 0.001$) and significantly faster than blue targets (25.55 ms, $t_{10} = 3.02$, $p = 0.013$), yellow targets (18.48 ms, $t_{10} = 3.91$, $p = 0.003$), orange targets (58.33 ms, $t_{10} = 4.85$, $p= 0.001$) and purple targets (44.88 ms, $t_{10} = 3.75$, $p = 0.004$).

Orange targets were found significantly slower than red targets (79.52 ms, $t_{10} = 6.55$, $p < 0.001$), blue targets (32.78ms, $t_{10} = 2.69$, $p = 0.023$), yellow targets (39.85 ms, $t_{10} = 4.24$ $p = 0.002$) and green targets (58.33 ms, $t_{10} = 4.85$, $p = 0.001$). There was no significant difference in reaction time between orange and purple targets (13.45 ms, $t_{10} = 1.11$, $p = 0.29$).

Purple targets were found significantly slower than red targets (39.77 ms, $t_{10} = 8.35$, $p < 0.001$), blue targets (19.34 ms, $t_{10} = 3.25$, $p = 0.009$), yellow targets (26.41 ms, $t_{10} = 2.56$, $p = 0.028$) and green targets (44.88 ms, $t_{10} = 3.75$, $p = 0.004$). There was no significant difference in reaction time between orange and purple targets (13.45 ms, $t_{10} = 1.11$, $p = 0.29$).

Table 1. Comparison of target colour effect on reaction time (ms)

	Red	Blue	Yellow	Green	Orange	Purple
Red		-46.74**	-39.67**	-21.19 **	-79.52 **	-39.77 **
Blue	+46.74**		+7.07	+25.55*	-32.78*	-19.34**
Yellow	+39.67**	-7.07		+18.48**	-39.85**	-26.41*
Green	+21.19 **	-25.55*	-18.48**		-58.33**	-44.88 **
Orange	+79.52 **	+32.78*	+39.85**	+58.33**		+13.45
Purple	+39.77 **	+19.34**	+26.41*	+44.88 **	-13.45	

*p<0.05, **p<0.01

4.2 Effect of Distractor Colour

Second, the effect of distractor colour on reaction time irrespective of target colour was analysed. A Repeated Measures ANOVA across all six target colour conditions revealed that there was a significant difference ($F_{5,50} = 6.49$, $p < 0.001$) in reaction time across the colours. Follow-up t-tests were therefore conducted to elucidate this difference. Figure 6 shows a graphical representations of the means analysed and the analyses are summarized in Table 2.

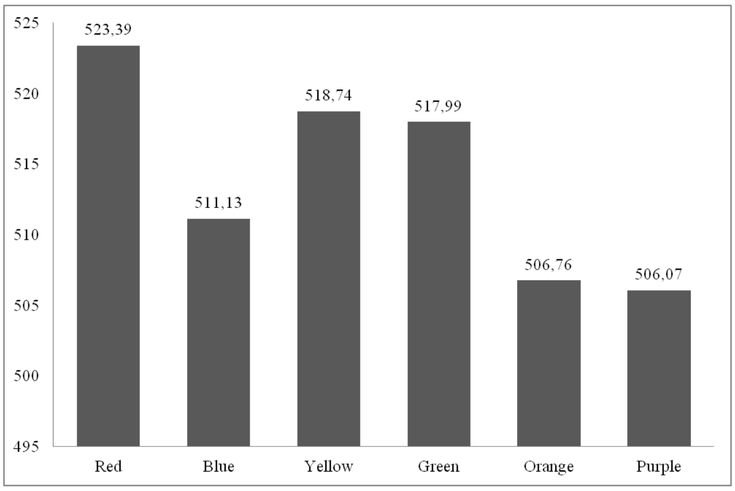

Figure 5. Reaction times (ms) for the distractor colours irrespective of target colour

Red distractors were associated with significantly slower reaction time than blue distractors (12.26 ms, $t_{10} = 3.75$, $p = 0.004$), green distractors (5.40 ms, $t_{10} = 2.65$, $p = 0.024$), orange distractors (16.62 ms, $t_{10} = 3.35$, $p = 0.007$) and purple distractors (17.32 ms, $t_{10} = 3.54$, $p = 0.005$). There was no significant difference in effect on reaction time between red and yellow distractors (4.64 ms, $t_{10} = 2.08$, $p= 0.065$).
Blue distractors were associated with significantly faster reaction time than red distractors (12.26 ms, $t_{10} = 3.75$, $p = 0.004$), yellow distractors (7.61 ms, $t_{10} = 2.39$, $p = 0.038$), and green distractors (6.86 ms, $t_{10} = 2.75$, $p = 0.020$). There was no significant difference in reaction time between blue and orange distractors (4.37 ms, $t_{10} = 0.97$, $p = 0.356$) or between blue and purple distractors (5.06 ms, $t_{10} = 1.62$, $p = 0.136$).
Yellow distractors were associated with significantly slower reaction time than blue distractors (7.61 ms, $t_{10} = 2.39$, $p = 0.038$), orange distractors (11.98 ms, $t_{10} = 2.23$, $p = 0.050$) and purple distractors (12.67 ms, $t_{10} = 2.52$, $p = 0.030$). There was no significant difference in effect on reaction time between yellow and red distractors (4.64 ms, $t_{10} = 2.08$, $p = 0.065$) or yellow and green distractors (0.75 ms, $t_{10} = 0.31$, $p = 0.762$).
Green distractors were associated with significantly slower reaction time than blue distractors (6.86 ms, $t_{10} = 2.75$, $p = 0.020$), orange distractors (11.23 ms, $t_{10} = 2.38$, $p = 0.039$) and purple distractors (11.92 ms, $t_{10} = 2.38$, $p = 0.020$) and significantly faster reaction times than red distractors (12.26 ms, $t_{10} = 3.75$, $p = 0.004$). There was no significant difference in effect on reaction time between green and yellow distractors (0.75 ms, $t_{10} = 0.31$, $p = 0.762$).
Orange distractors were associated with significantly faster reaction time than red distractors (16.62 ms, $t_{10} = 3.35$, $p = 0.007$), yellow distractors (11.98 ms, $t_{10} = 2.23$, $p = 0.050$) and green distractors (11.23 ms, $t_{10} = 2.38$, $p = 0.039$). There was no significant difference in effect on reaction time between orange and blue distractors (4.37 ms, $t_{10} = 0.97$ $p = 0.356$) or between orange and purple distractors (0.69 ms, $t_{10} = 0.18$, $p = 0.863$).
Purple distractors were associated with significantly faster reaction time than red distractors (17.32 ms, $t_{10} = 3.54$, $p = 0.005$), yellow distractors (12.67 ms, $t_{10} = 2.52$, $p = 0.030$) and green distractors (11.92 ms, $t_{10} = 2.38$, $p = 0.020$). There was no significant difference in effect on reaction time between purple and blue distractors (5.06 ms, $t_{10} = 1.62$, $p = 0.136$) or between purple and orange distractors (0.69 ms, $t_{10} = 0.18$, $p = 0.863$).

Table 2. Comparison of distractor colour effect on reaction time

	Red	Blue	Yellow	Green	Orange	Purple
Red		+12.26 **	+4.64	+5.40*	+16.62**	+17.32 **
Blue	-12.26 **		-7.61*	-6.86 *	+4.37	+5.06
Yellow	-4.64	+7.61*		+0.75	+11.98*	+12.67*
Green	-5.40*	+6.86 *	-0.75		+11.23*	+11.92*
Orange	-16.62**	-4.37	-11.98*	-11.23*		+0.69
Purple	-17.32 **	-5.06	-12.67*	-11.92*	-0.69	

*p<0.05, **p<0.01

5 DISCUSSION

In this paper we presented a study of the attentional capture of red, blue, yellow, green, orange and purple. In accordance with our main hypothesis, different colours were associated with different degrees of attentional capture, with red capturing attention significantly more than all other colours and purple and orange capturing significantly less attention than the remaining. To explain why different colours capture attention differently, we proposed and investigated what we referred to as the perceptual-primacy account and the emotion-conveyance account. In the following sections, we discuss the evidence for and against each of these two accounts, as well as potential implications for the disciplines of design and psychology.

5.1 The Perceptual-Primacy Account

The perceptual-primacy account states that colours denoted as primary colours receive preferential processing and thereby capture attention to a larger extent. We here investigated two versions of this account: one which denotes the primacy of colours based on our retinas, which posits that red, green and blue are the primary colours, and one which denotes the primary colours based on the properties of pigments, which posits that the primary colours are red, blue and yellow.

Our results show support for both versions of the perceptual-primacy account: Red and green targets were found significantly faster than blue and yellow targets, which in turn were found significantly faster than orange and purple targets. In accordance with the notion of higher attentional capture of these colours, it was further found that, with one exception, average search times were slowed significantly more when a red, blue, yellow or green distractor was present.

However, there were significant differences in search times amongst the primary colours when compared both on their role as a target and a distractor. Of these, two were especially notable: One, with a single exception, red always captured significantly more attention than all other colours. Two, yellow performed differently compared to the other colours as a target and a distractor; when comparing targets, yellow captured significantly more attention than green, and did not differ from blue, when comparing distractors, yellow captured significantly more attention than green and was not significantly different from red in its effect. While these findings are not in disagreement with the perceptual-primacy account, they do suggest that other factors influence differences in attentional capture from colour as well. We discuss these alternate accounts below, beginning with the emotional-conveyance account.

5.2 The Emotional-Conveyance Account

The emotional-conveyance account states that colours convey emotions to a sufficiently salient degree and at a sufficiently early stage of processing to influence attentional capture. We here investigated this account by comparing colours associated with ‘action moods’ with ‘soothing and relaxing moods’. This assumed that if colours convey emotions at an early stage then the colours associated with particularly salient colours would receive preferential processing.

Our results showed evidence against the emotional-conveyance account, albeit inconclusively. In support of the emotional-conveyance account, red, which, as stated in the introduction, is associated with exciting and defying/hostile moods, captured significantly more attention than any other colours as both a target and all colours but yellow a distractor, which was not significantly different to red. Furthermore, yellow, which is associated with exciting moods, captured the same amount of attention as red, and more attention than any other colour as a distractor. However, yellow targets were not found significantly faster than red, blue or green and orange, which is also associated with exciting moods, consistently captured the least amount of attention alongside purple. The results thus indicate that exciting and relaxing moods were not conveyed at a sufficiently early stage to influence attentional capture. Furthermore, given that red did not always capture attention more than other colours, it seems unlikely that the emotion-conveyance account explains the observed differences.

5.3 Alternate Accounts

Given that neither the perceptual-primacy account or emotional-conveyance account were completely congruent with the data, we here discuss two potential alternate influencing factors.

First, it is possible that training effects and conventional uses of the colours have influenced the search tasks. For example, red is commonly used in traffic and to signal important information for emergencies. Participants may therefore be trained in searching for red, which would explain why red showed significantly more attentional capture as a target, but was not significantly different from yellow in attentional capture as a distractor. Second, it may be that we are inherently predisposed towards certain colours due to other biological factors than the ones considered here, such as gathering of certain foods or similar.

5.4 Insights for Designers

Our results showed colour mediated differences in reaction time in a visual search task. Furthermore, we found that it is unlikely that colours convey moods and emotion until conscious processing has occurred.

While the differences were on the scale of tens to hundreds of milliseconds, these effects may be amplified in contexts of higher visual load (Lavie and Tsal, 2004), or simply add up over time. We therefore propose that visual designs should use red or green for objects that are particularly important for the user to find quickly, and to avoid using red and yellow for miscellaneous objects in an interface, as they would interfere with visual search. Furthermore, our results suggest that designers will not be successful in rapidly conveying emotion or mood tones through colour.

5.5 Insights for Psychology

Studies of the degree to which colour can capture attention have thus far shown diverging results (Folk et al., 1994; Theeuwes, 1994; Müller et al., 2009). In the light of our finding that different colours have different attentional effects, we suggest that future studies should either replicate the choice of colours used by their predecessors, or, preferably, to investigate attentional effects for an array of different colours, given that the results might diverge in accordance with the colours used in the experiment design.

On a more general note, our results imply that great care should be taken in experiment designs where colours are used to indicate specific objectives for the experiment. For example, when conducting a partial report task, one may for example be asked to report all red letters and to ignore blue letters. Our results indicate that these types of tasks could be biased simply by the colours used, rather than any other properties one may have wanted to investigate. To avoid this, careful choice of colours and/or counterbalancing would be necessary.

6 CONCLUSION

In this paper, we presented a controlled-environment study of the attention-capturing properties of red, blue, yellow, green, orange, purple. Specifically, we tested whether effects could be explained through a primary-secondary colour dichotomy and/or through differences in emotional conveyance of colours. We found significant differences in attentional capture between primary and secondary colours, defined both from a biological and design perspective. Notably, red captured significantly more attention than other colours, while orange and purple consistently captured the least attention. However, we did not find substantial evidence to support that colours convey emotions at an early enough stage to affect attentional capture. Alternate accounts and impacts for design and psychology were discussed.

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